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Department
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Alternative Materials for One Cent Coinage

ALTERNATIVE MATERIALS

FOR

ONE CENT COINAGE

DEPARTMENT OF THE TREASURY

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INTRODUCTION

Purpose

In July 1973, growing concern over both the rapidly increasing cost of copper and the rising demand for pennies compelled the Treasury Department to initiate a Treasury Department-Federal Reserve study under the direction of the Bureau of the Mint. A study committee was assigned the tasks of:

(1) preparing a contingency plan for an alternative metal alloy for the cent;

(2) recommending whether a strip production or strip storage facility should be incorporated in the new Denver Mint; and

(3) analyzing demand forecasting and production control models in order to improve the accuracy of long and short term coinage forecasts.

(See Appendix A - A Study of Future Cent Demand and Materials - Project Plan).

This report is concerned with the first two objectives of the study - namely, recommendation of a new material for the penny and a discussion of the impact of this recommendation on plans for the new Denver Mint. A subsequent report, to be issued in approximately four months, will provide recommendations on coinage demand forecasting and production control procedures.

Background

Approximately 75 percent of the Mint's coinage production is for one-cent coins. In 1974, the Bureau of the Mint plans to produce more than 7 1/2 billion pennies requiring approximately 50 million pounds of

copper. These 7 1/2 billion coins, worth $75 million in terms of face value, will cost the U.S. Treasury $66 million to produce - of which $51 million represents the metal content at current prices. The cost of copper is threatening to increase beyond the "break-even point" for penny production and it is necessary that alternative materials for one-cent coins be seriously considered. A 95 percent copper - 5 percent zinc alloy ("penny bronze" or "gilding metal") is now utilized for pennies.

During the first eleven months of 1973, the purchase price of copper on world markets increased from 50¢ to more than $1.00 per pound. If the price were to continue to increase to beyond $1.20 per pound, the cost of producing the bronze 95 percent copper - 5 percent zinc cent, including material, labor and transportation costs, would exceed the value of the coin.

At a copper price of $1.50 per pound, the intrinsic value of the metal in the coin would exceed the face value and pennies would become an inexpensive source of copper. If this situation were to occur, demand would increase drastically beyond the Mint's production capacity. The Mint would then be unable to satisfy demand at any cost and a severe coin shortage would result.

Preliminary recommendations from the study committee for an alternative coinage material were scheduled for February 1974. However, the large savings which would accrue if the cent material were changed to a less expensive alloy, coupled with a resumption in copper price increases during October 1973 after a deescalation trend in August and September, have resulted in an accelerated research and development effort, culminating in recommendations for consideration by the Director of the Mint and the Secretary of the Treasury.

Methodology

A list of objective criteria was prepared for assessing the suitability of alternative coinage mate-

rials. An extensive roster of possible materials was then appraised against the criteria and a small group of materials was selected for an extensive examination of metallurgical, technical and economic characteristics. A critical part of the study was a thorough exploration of the supply and demand situation for copper and those metallic elements which are important constituents of the most promising candidate materials.

Since the Mint is in the process of designing a new coining and metal strip facility to replace the present Denver Mint in 1980, it was necessary to consider the impact of a new one-cent material on plans for the new Denver Mint. Accordingly, visits were made to industrial facilities in which the most promising candidate materials are produced in the form of strip suitable for coinage blanks.

Acknowledgements

The study of alternate coinage materials was directed by Dr. Alan J. Goldman, Chairman of the Treasury Department - Federal Reserve Board study committee. He was assisted by Dr. George E. Hunter, C. William Smith, Jr., William J. Murphy and Richard E. Schmidt. Mark Shreeve of the Bureau of the Mint's Office of Technology performed the coining studies and assisted in the preparation of those parts of the report which concern coinability of the alternative materials.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

It is recommended that the composition of the cent be changed to an alloy containing not less than 96 percent aluminum. The size and design of the penny should not be altered. The highest feasibility materials and the present cent material are compared in Table 1. An aluminum alloy cent is preferred when compared with other candidate materials including the currently utilized 95 percent copper - 5 percent zinc alloy for the following reasons:

1. In recent weeks, the market price of copper has increased to more than $1.00 per pound and the Treasury Department's seigniorage* on one-cent coins is seriously threatened. An annual savings in raw materials exceeding $35 million would be realized at current penny production levels if an aluminum alloy were used for one-cent coins. This saving is based on market prices for copper and aluminum of $0.90 and $0.30 per pound respectively.

2. Aluminum can be more economically fabricated into one-cent coins at an annual savings in manufacturing and transportation costs of more than $500,000. Most of this savings is a result of the fact that coin blanks punched from aluminum strip do not require a high temperature softening treatment prior to coining.

*Seigniorage represents income to the U.S. Treasury resulting from transfer, at face value, of coins from the Mint to the Federal Reserve. Its value is the difference between face value and metal cost.

3. The outlook for future supplies of refined aluminum and aluminum alloy strip in the United States is favorable. Furthermore, a change in penny material would have a negligible impact on the aluminum and copper alloy strip markets. The Mint would utilize less than 0.5 percent of the total aluminum alloy strip fabricated in the United States. The strip now purchased for bronze cents represents approximately one percent of the copper alloy strip produced domestically.

4. Aluminum coins have been accepted by the public in several developed countries including Italy, Japan, Austria, and Finland. The composition of the Finnish one penni coin was changed from bronze to aluminum without any problem of public acceptance.

5. Aluminum cents of the same size as the bronze cent will not cause difficulties to users and manufacturers of coin counting, dispensing, wrapping and simple vending devices such as bubblegum machines. Sophisticated vending machines which accept and discharge cents and automatic toll booth systems which accept pennies will require some modification.

6. The wear-corrosion characteristics of aluminum compare very favorably with 95 percent copper - 5 percent zinc and other substitute materials which were studied.

It is recommended that the change to aluminum be effected as soon as possible in order that the Mint's production capacity not be strained by a penny shortage. A rapid, large scale withdrawal of cents from circulation is probable if the price of copper continues to rise toward a level where one-cent coins become an economically attractive source of copper.

Accordingly, draft legislation has been prepared which, if it is enacted by Congress, would give the Secretary of the Treasury the authority to change the one-cent material to an alloy containing not less than 96 percent aluminum.

In keeping with the Bureau of the Mint's policy of having the capability of producing a large percentage of its required metal strip in-house, it is recommended that a facility for casting and rolling aluminum alloy strip be included in plans for the new Denver Mint.

REVIEW OF THE COST TO PRODUCE A BRONZE CENT

Cost of Raw Materials

From 1959 through 1963 the value of the raw materials in the 95 percent copper and 5 percent zinc penny remained approximately constant at 0.20¢ per piece or approximately 1/5 the face value of the coin. An escalation in copper prices occurred in 1964 and, although large fluctuations occurred in the price of copper during the period 1964 to 1970, the average annual value of the metal cost in the cent fluctuated in the range of 0.28¢ to 0.47¢ per piece in the period 1964 to 1972. The trend is indicated in Figure 1 where the annual average copper price and the metal value of the cent are shown for the period 1959-1972.

Biweekly average prices for copper and the metal value of the cent for the first eleven months of 1973 are indicated in Figure 2. The generally escalating trend to a metal value exceeding 0.60¢ per piece in July 1973 resulted in the formation of a study committee to seek alternative materials in case the price of copper continued to increase at a rapid rate. The intrinsic value of the metal in the cent will exceed the face value of the cent at a copper price of $1.50 per pound.

Other Costs

Other costs incurred in the production of cents by the Bureau of the Mint, in addition to the cost of raw materials, include: (1) Manufacturing costs to fabricate bronze strip and coins; (2) Transportation charges for shipping raw materials and finished coins; and (3) Broker profits on the purchase of copper on world markets. The total of these costs is approximately 0.20¢ per piece or $0.30 per pound with item (1) accounting for approximately 85 percent of these totals. It should be noted that these costs are in-

creasing at an annual rate which exceeds 5 percent.

The "break-even" point for the production of bronze cents is, therefore, $1.20 per pound for copper (0.8¢ per piece for metal). At prices above this level, the total cost to produce a penny, including metal content, would exceed the face value of the coin.

Factors Influencing Present Copper Market

Soaring demand and severe production, economic, technical and political dislocations in copper producing countries such as Chile and Zambia have resulted in a shortfall between supply and demand of 350,000 to 450,000 tons of copper in world markets in the third quarter of 1973[1]. An economic slowdown is projected for certain parts of the world economy in 1974. This is likely to cause a decrease in the rate of growth of free world copper consumption. However, a majority of the labor contracts in United States copper mining firms and copper alloy fabricators expire in mid-1974 and this will probably result in vigorous hedge buying for the next several months.

Industrial leaders at a recent forum in London predicted that the world price for refined copper would rise to $1.05 per pound in the next two <u>months</u>[2]. Approximately two <u>weeks</u> after the prediction was made, the market price of copper reached $1.05. It is evident that the government must be prepared for the possibility that cents will be produced at a cost which exceeds the face value of the coin unless a cheaper material is substituted for the bronze alloy which is currently being used.

[1,2] A list of references may be found on page 50.

CRITERIA FOR EVALUATING ALTERNATIVE ONE-CENT MATERIALS

The essential function of a coin is to act as a reliable medium of exchange. Several criteria must be considered when selecting a coinage material. The relative importance of the criteria set forth below are dependent, to a large extent, on the fact that this study is concerned only with the lowest value denomination, the cent. Factors such as counterfeiting potential, which are of primary importance when considering higher value coinage, are relegated to secondary importance in evaluating alternative materials for the cent. On the other hand, pennies account for approximately 75 percent of the Bureau of the Mint's production as measured by number of pieces and approximately 65 percent of the Mint's utilization of raw materials. This dictates that raw materials cost, availability, and ease of production be criteria of primary importance. With this perspective, specific criteria are reviewed below.

Cost, Availability and Permanence

The coinage material should be consistent with the goals of minimizing cost to the public and maximizing Treasury "profit" (seigniorage). The intrinsic value of the metal should be significantly less than the face value of the coin in order to provide a margin of safety for future increases in the price of the raw material.

In order to assure an adequate present and future supply of the coinage material, it is imperative that ores and refined metals be available from domestic or reliable foreign sources. It would certainly be imprudent to depend on a foreign source for raw materials if there were a strong indication that supplies might be interrupted because of a threat of expropriation, revolution, strikes or other unsettling factors.

For price stability, minimal market disruption and reasonable assurance of a reliable supply of rolled strip from domestic sources are essential. Commercial production of the coinage alloy should be many times greater than Mint requirements.

Coinage materials must be available at acceptable costs for a minimum of 15 years since there is a risk of a coin shortage each time the value of the raw material approaches the face value of the coin. A shortage due to withdrawal of coins from circulation cannot be alleviated immediately by changing materials. Coin shortages are remedied only after the entire circulating pool has been replenished and this may take one to five years. In addition, changes in coinage materials occurring more frequently than 15 to 20 years may require substantial capital investment in Mint plant and equipment.

Energy consumption in the production of various materials affects their costs and availability and must also be considered.

In summary, the substitute one-cent material should be readily available for several years at a cost which will guarantee that pennies will not become a desirable source of an expensive, scarce raw material.

Minting Characteristics and Coining Costs

Relative ease in the manufacturing processes for a new one-cent piece is particularly desirable in view of the fact that cent production accounts for three quarters of the Mint's coinage output. In order to minimize the possibility of a cent shortage without expending large sums for new processing machinery, the selected substitute material must be readily fabricated into pennies using equipment which is presently in operation at the Bureau of the Mint's coining facilities.

It is also desirable, as a simple matter of efficiency, to minimize the cost of manufacturing coins of acceptable quality. It is axiomatic that the Treasury should seek to achieve the lowest possible total coinage cost, inclusive of materials used. This dictates that

the substitute material be one which results in minimum material costs, strip fabrication costs, minting costs and transportation costs. At the same time the new material must result in a one-cent piece which is acceptable to the public.

Public Acceptability

The main elements of acceptability will be (a) demonstrated necessity of the change, (b) characteristics of the new coins, (c) degree of inconvenience to which the public is subjected by the change, and (d) the absence of extreme hardship suffered by any particular industry as a result of the change.

a. Need for the change

In view of the rapidly rising price of copper, present and prospective, and the threat that production costs for cents (inclusive of raw materials cost) will exceed the face value of the coin in the near future, it is essential that a less expensive coinage material be substituted for the 95 percent copper - 5 percent zinc alloy.

b. Characteristics of the new coins

The new coins should be durable, easily distinguished from the other denominations and be made of a non-toxic material. The coins must have an attractive, lustrous appearance. A history of acceptance of a similar alloy for coinage in highly developed foreign countries is considered a positive factor. Color and "feel" are not essential to the transactional function of the cent and consequently are less important characteristics. Counterfeiting potential is another property of secondary importance because of the low value of the cent and its minor importance in vending machine usage compared with other denominations.

c. Degree of inconvenience

Inconvenience to the public will be minimal if new coins have the desirable technical characteristics, are readily available and can be used in the small proportion of coin operated devices which accept cents. A smooth transition can best be facilitated if both the old and new coins are permitted to circulate freely without any requirement that the public exchange old coins for new.

d. Absence of extreme hardship

A new coinage material must not inflict a demonstrably serious hardship on a particular group or industry. The coin machine industry could claim a hardship if new coins did not work in its machines. Cents are used in counting, sorting, and coin-wrapping machines, some toll booths and vending machines, change-makers, parking meters, and cash register dispensers. Any new material cent must be useful in most of the present machines. It is desirable that very few, if any, modifications be required to avoid machine obsolescence. For this reason, changes in diameter or thickness of cents were dismissed from further consideration.

New coins and old coins must be able to be used indiscriminately in most machines, i.e. the new must not be inherently incompatible with the old.

A description of coin machine operations is given below.

(1) Counting and wrapping machines accept loose coin of any one denomination, pass it rapidly through a small turnstile for count, and drop it into a tube or bag for

wrapping. Electro-optical counting has just been introduced by two manufacturers.

(ii) Sorting and counting machines accept loose coin of several denominations, separate it by denomination, and count numbers of coins of each denomination. There are two common types: drum and rail. The rail type is faster but requires a separate counting machine for each denomination. Both are in common use.

(iii) Most vending machines which accept cents are of the simple bolt or wheel type found on bubblegum machines and parking meters.

One sophisticated machine has just been introduced to accept cents and other coins, vend merchandise, and dispense cents and other coins as change. There is much disagreement within the vending machine industry as to whether this type of machine will be widely accepted[3] .

(iv) Most toll booths discourage the use of cents by means of "NO PENNIES" signs. This is done because cents often jam these machines by overloading the vibrating chute and allowing two coins to arrive simultaneously at the sorting module.

(v) Change-makers dispense cents and other coins from filled tubes by means of a sliding pusher at the bottom of the tube.

METALLURGICAL, TECHNICAL AND ECONOMIC CHARACTERISTICS OF ALTERNATIVE COINAGE MATERIALS

Survey of Candidate Materials

1. Copper-Zinc Alloys

A wide range of common copper-zinc alloys are utilized commercially for products requiring high formability and pleasing appearance. The major effects of substituting zinc for copper are to (1) decrease the raw material cost of the alloy since the price of zinc is lower than the price of copper and (2) change the color from a red bronze at 5 percent zinc to a yellow brass at 30 percent zinc. Historically, the price of zinc has been approximately one third the price of copper. The effect of zinc content on the material cost per one-cent piece is shown in Figure 3 for both the present prices of copper and zinc and prices at which the metal value of the copper - 5 percent zinc cent reaches one-cent. At current prices, the metal value of the cent could be reduced 17 percent from approximately 0.6¢ per piece to 0.5¢ per piece by utilizing an alloy containing 70 percent copper and 30 percent zinc. At current production levels, this would represent a saving of $8 million.

The economic benefits mentioned above resulted in the inclusion of the following copper-zinc alloys in the list of high feasibility materials for further study: 90 percent copper - 10 percent zinc, 87 percent copper - 13 percent zinc, 85 percent copper - 15 percent zinc and 70 percent copper - 30 percent zinc.

2. Aluminum Alloys

Aluminum alloys are used for low denomination coins in several countries including developed industrial countries such as Italy, Japan and Austria. Eight years ago, Finland substituted an aluminum alloy for bronze in the one penni piece. The new material was accepted by the public without protest.

The savings which would be realized in raw material costs if aluminum were used for cents are very large. Figure 4 shows the annual savings in millions of dollars as a function of copper price for three

levels of cent production. The price of aluminum has fluctuated in the range of 20-30¢ per pound in recent years (See Figure 5) and a price of 30¢ was assumed for the data in Figure 4. An annual savings exceeding $35 million could be realized at current production levels if the cent were made of an aluminum alloy. This annual savings is even more dramatic at anticipated future production levels.

Three aluminum alloys were chosen for further study. Table 2 shows the chemical composition of commercially pure alloy 1100 and two alloys, designated 3003 and 5052, which contain additional elements for improved hardness and wear resistance.

3. Chromized Steel

Many steel coating processes have been developed to provide a wide range of desirable properties. One of these processes, chromizing, employs a high temperature treatment to form an iron-chromium alloy coating on low cost sheet steel. Chromized steel is a material having the surface characteristics of stainless steel and a price which is less than 25 percent that of penny bronze. Although chromizing is a proprietary process developed by Bethlehem Steel Corporation, the desirable surface characteristics and relatively low cost of chromized steel dictated that it be considered as an alternative cent material.

4. Bronze Clad Steel

Cladding is a manufacturing process for metallurgically bonding sheet materials. The United States is now using cupro-nickel clad copper coinage for dimes, quarters, half dollars and dollars as a substitute for the traditional silver coinage.

Copper-zinc alloys clad on low cost sheet steel have been used for coins in West Germany for many years. This class of three layer clad products offers the surface characteristics of copper-zinc alloys at a reduced total cost of raw materials. A clad material

consisting of 90 percent copper - 10 percent zinc clad on both sides of mild steel was studied as candidate replacement material for penny bronze.

5. Stainless Steel

Coins made of stainless steels have an attractive luster and superior resistance to wear and corrosion. However, stainless steel has two disadvantages which eliminated it from further consideration. The prices of various stainless steels are higher than any of the substitute materials mentioned above and most stainless steels are more costly than penny bronze. In addition, its hardness requires that stainless steel coins be made with very low relief of image and lettering above the coin background.

6. Zinc Alloys

In 1943, zinc plated on steel was used as a substitute for penny bronze in order to conserve copper. Zinc and its alloys have a silvery appearance but oxidize to a dull gray appearance after a period of use. After ten to fifteen years of handling, zinc alloys take on an unacceptable dark gray appearance. After examining several zinc Austrian coins which had become almost black, it was decided that zinc alloys do not merit further consideration.

7. Plastics

There are no known instances of the use of plastic as a coinage material and it was rejected from consideration on the basis of three factors: (1) The growing world wide shortage of petroleum derivative products has caused an inadequate supply of plastics to meet current and projected industrial demand; (2) It is highly improbable that plastic coins would be acceptable to the public; and (3) A large capital expenditure for equipment would be required to produce large quantities of plastic coins.

8. Other Clad Materials

Cursory consideration of various clad materials would appear to yield several possible combinations of attractive, economical, and coinable three layer materials. However, further study eliminated all but bronze clad steel as a possible substitute material. For example, aluminum clad steel and cupronickel clad zinc were eliminated because the temperature required to soften the harder constituent would melt the softer component. Nickel clad steel and stainless steel clad aluminum are not economically attractive because of probable low die life and high bonding costs.

In summary, after reviewing the merits of several candidate materials the following were chosen for more detailed consideration: copper-zinc alloys; aluminum alloys; chromized steel; and bronze clad steel.

Supply-Demand Trends 4-7

Availability of raw materials for at least 15 years is a requisite for substitute alloys. Furthermore, materials must be obtainable at prices which will insure that frequent changes in materials will not be required to protect seigniorage. As a result, the supply-demand characteristics of elements which constitute the candidate materials were reviewed in detail. Table 3 summarizes the domestic and world production and usage of aluminum, copper, iron, zinc, chromium, magnesium and manganese. Copper, aluminum and iron are major ingredients and the remainder are minor constituents of the materials under consideration as substitutes for gilding metal. Each of the elements is discussed below in terms of the characteristics of the world and domestic markets including projections into the future.

1. Copper

The United States is the leading copper producing country in the world. In 1971 this country produced over 1.5 million short tons of copper ore which was 23 percent of the total world production. Chile, Canada and Zambia, the next three leading producers of copper ore, produced a combined total of 2.2 million short tons which was 34 percent of the total world production. In 1971 the United States produced about 1.8 million short tons of refined copper which filled over 80 percent of the domestic demand of 2.1 million short tons of refined copper.

The present consumption of copper in one-cent coins is approximately 1 percent of the total domestic consumption of the raw material. The Mint's usage of bronze strip is approximately 2 percent of the copper alloy strip produced in the United States. Only 40 percent of the bronze strip utilized for cents is purchased from copper alloy producers. The remainder is manufactured in-house at the Philadelphia and Denver Mints.

The long range projections of domestic copper demand indicate that by the year 2000 the United States will need about 7.1 million short tons of refined copper per year and that the cumulative demand from 1971 through 2000 will have been about 92.7 million short tons. Domestic reserves in the U.S. are more than adequate to meet this demand. The world demand for copper in 1972 was about 8.7 million short tons. By the year 2000 the world demand is projected to be 31.5 million tons annually and the cumulative world demand from 1971 through 2000 will have been 392.6 million short tons. In summary, both the U.S. and world reserves of copper are adequate to meet both the U.S. and world demand through the year 2000. We can, however, anticipate rising prices (in constant dollars) as the demand increases.

Prices of copper, in terms of constant 1971 dollars, increased from $.39 per pound in 1959 to $.52 per pound in 1971. Recently prices have risen sharply. In November 1973 the price of copper reached a level above $1.00 per pound. This increase was due primarily to a generally buoyant economy with concurrent increases in the demand for copper. There were political problems and strikes in Chile and Peru in 1973. These conditions as well as transportation and other logistical problems in Zambia, adversely affected the supply of copper to world copper markets. The supply shortage, combined with the high level of demand, has driven prices upward.

The largest domestic use of copper is in electrical equipment and supplies. Electrical wiring, test equipment, power generation and distribution systems, sophisticated electronic navigation and communications systems require large quantities of copper. The non-corrosive properties of copper also result in many uses in the construction industries for roofing and plumbing. Copper alloys are also used extensively in the production of non-electrical machinery, in the transportation industry and in the manufacture of ordnance.

In projecting future demands, it is essential that several factors be considered. These include possible

substitution of other materials such as aluminum and aluminum clad copper for copper in some applications if the present price differential persists or increases. On the other hand, increased usage of electrical energy compared with energy generated from combustion of petroleum and its derivatives is likely to greatly increase demand for copper.

The environmental considerations in both the mining and manufacture of copper are formidable. The mining operation scars the land and surface restoration presents a major ecological problem. Because one ton of water is required per ton of ore processed, adequate water supplies must be available. During the smelting operation sulfur is emitted into the atmosphere causing air pollution. Pressures to reduce SO_2 emissions at copper smelters through proposed stringent regulations are retarding decisions on needed increases in smelting capacity. These environmental problems can be solved but only at a significant increase in production costs.

Another major problem that the copper industry faces is a generally declining yield of copper from ore in the United States. The yield has dropped from an average of 18 pounds of copper per ton of ore in 1950 to 11 pounds per ton in 1971. Some copper deposits currently under development contain only 8 pounds of copper per ton of ore.

The long range projections regarding supply, demand, environmental problems, and technological advances reflect the most accurate extrapolation of data that can be made at this time. The short range projections are that the price of copper will continue to rise because many domestic copper mining and strip producer labor contracts expire in mid-1974. This will keep prices up during the next six months as consumers try to accumulate larger inventories. While the long range projections are far from absolute in determining precise economic data, the general trend seems to indicate that considering all factors the price of copper, in constant dollars, can be expected to increase.

2. Aluminum

Aluminum is the most abundant metallic element in the earth's crust. Bauxite, the ore most commonly used as a source of aluminum, is found primarily in the less industralized areas of the world. The leading world producer of bauxite in 1971 was Jamaica where 2.8 million short tons were produced. Of this total, 1.7 million tons were imported into the United States. Other leading world producers were Australia (2.8 million tons) and Surinam in Northeastern South America (1.7 million tons). In 1971 the United States produced .5 million short tons of bauxite domestically, primarily in Arkansas.

The total U.S. demand for refined aluminum metal in 1971 was 4.1 million short tons. Although domestic refineries accounted for 3.9 million tons of aluminum metal which satisfied 95 percent of this demand, only 12 percent of our raw materials requirements were supplied from domestic sources.

The world demand for aluminum in 1971 was 13.3 million short tons. By the year 2000 the world demand is projected to be 81.3 million tons. World reserves are estimated at 3 to 6 billion tons and the potential world supply for at least a century is virtually unlimited. Many of the major bauxite deposits are owned by domestic firms. However, taxes and royalties on bauxite mining in foreign countries are expected to increase and since the U.S. currently depends on imports of bauxite for more than 85 percent of its requirements, domestic prices of refined aluminum can be expected to increase. Figure 5 shows that the domestic price of aluminum has varied over a very narrow range during the past 15 years.

Although bauxite is now the main aluminum resource domestically and abroad, the ultimate aluminum resources are expected to be non-bauxite clays of the kaolin type, anorthosite and alunite. The United States has large supplies of such materials and could meet all or most of its aluminum raw materials needs indefinitely if domestic firms exploit these alternate sources of aluminum. At the current price of aluminum of less than $0.30 per pound and the availability of bauxite and alumina from

foreign sources at reasonable prices, it is economically more advantageous to import large quantities of these raw materials from Jamaica, Surinam, and Australia than develop domestic clays on a large commercial scale.

Alunite is used as an economical source of aluminum in the Soviet Union. Processing of alunite yields useful byproducts, including potassium sulfate, which may make it economically competitive to bauxite. A pilot plant to extract aluminum from alunite is being built in Utah by two domestic firms.

An anorthosite deposit, owned by Alcoa and located in Wyoming, is thought to exceed all the world's known bauxite reserves. Research and development aimed at reducing the cost of extracting aluminum metal from anorthosite and other non-bauxite aluminum containing clays is being actively pursued by the Bureau of Mines. It is not unreasonable to expect that technological advances would make it economically more attractive to extract aluminum from clays and thereby eliminate our dependence on foreign ore for aluminum.

The largest domestic use of aluminum is for building and construction items such as residential siding, mobile homes, doors, windows, roofing, curtain walls, screening, bridge and guard rails, pre-engineered structures and other bridge, street and highway uses. The transportation industry is another major consumer where aluminum is used in automobiles, trucks, railroad cars, ships, and aircraft. Aluminum is also used in virtually all types of cans and containers as well as in the electrical and communications industries. It is also used for appliances as well as industrial and agricultural machinery.

Aluminum is a durable metal that deteriorates very slowly. The recycle time for old aluminum scrap varies from a few months (for special industrial uses) to 30 years or more (for other uses such as aircraft and shipbuilding). The quantity of old scrap recycled during 1971 was approximately 5 percent of the total

demand for aluminum metal. The fact that aluminum products do not deteriorate rapidly is a mixed blessing because it poses a disposal problem. However, in recent years there have been increasing efforts by the major domestic producers to recycle discarded aluminum products. Collection centers have been established throughout the country and 0.25 million tons of aluminum were recovered in 1971 from old scrap.

There are environmental problems associated with the production of aluminum. The disposal of solid wastes (red muds) generated in producing alumina from bauxite results in the creation of large red mud lakes. Fluorine-containing dust and gases emitted from the electrolytic refining process pollute both the surrounding water and air. Careful operating procedures can minimize this source of pollution and a shift to a fluoride-free electrolyte is a possible future technological advancement.

In summary, while the domestic supply of bauxite is limited, it is very plentiful throughout the rest of the world. Other aluminum bearing ores are available in the United States and may be exploited commercially by 1980. The abundance, low price, high electrical and thermal conductivity, and durability of aluminum will result in an ever increasing demand as other metals become more costly.

3. Iron

The leading world source of iron ore in 1971 was the U.S.S.R. which produced 132 million tons. This represented approximately 27 percent of the total world production of 488.4 million tons. Other significant producers were the United States (54.3 million tons), Australia (43.8 million tons), Brazil (31.5 million tons), Peoples Republic of China (30.2 million tons) and Canada (30.1 million tons).

The importance of iron to an industralized economy makes it mandatory that any highly developed country fulfill a large fraction of its requirements from dom-

estic sources. The United States is able to satisfy 75 percent of its needs from domestic sources and reclaimed scrap plays an important part in enabling the U.S. to keep imports at a minimum. Domestic scrap totaled 33.4 million tons in 1971. Imports totaled 28 million tons, the bulk of which was in the form of ore (27.7 million tons). The major external sources of iron ore are Canada and Venezuela. Domestic ore production could be increased to meet the total domestic need, but only with a relative sacrifice in ore quality, or increase in cost over imported ore.

The United States demand for refined pig iron in 1971 totaled 108.1 million tons while domestic production totaled 81.4 million tons. This was second only to the Soviet Union's production of 97.3 million tons of pig iron. Other leading producers of refined iron in 1971 were Japan (80.2 million tons), West Germany (32.8 million tons) and China (30 million tons). The world produced 474.2 million tons of pig iron in 1971.

The long range projections of domestic iron demand indicate that by the year 2000 the U.S. will need about 220 million tons of iron and the world total requirement will be 1,260 million tons. Domestic resources of iron ore are estimated to be 2,000 million tons and total world reserves are estimated at 96,700 million tons. While iron-bearing substances are widely distributed throughout the world, three factors are important in determining the degree to which they can be classified as ore: quality, in terms of yield of iron and prevailing extraction technology; accessibility, in terms of competitive position with regard to other available sources; and security, in terms of the extent to which supplies are insured.

Iron ore prices have been relatively stable over the last 20 years. Worldwide prices began rising somewhat in 1970 as several foreign producers obtained

higher prices for future export contracts. The 1971 price of iron ore was $17.20 per ton and the price is expected to reach $20.30 per ton by 2000.

The average price of basic pig iron ranged from $47.39 per ton in 1952 to $68.68 in 1971. The October 1973 price for pig iron was $71.15 per ton. This is equivalent to less than four cents per pound.

Approximately 90 percent of the pig iron produced is used in steel making. Most of the remainder goes to foundries to make castings, pipe, and machinery parts. The many varieties of steel are used in the production of motor vehicles, ships, railroad equipment, pipe and tubing, construction products, containers, appliances, machinery tools, cutlery, and hundreds of other miscellaneous items.

4. Zinc

In 1971, the United States was the third largest producer of zinc ore in the world and the leading producer and consumer of refined zinc. Fifty percent of the total domestic imports of ore and zinc metal in 1971 were supplied by Canada which led the world in ore production. Total domestic slab zinc production in 1971 was 847 thousand short tons. This satisfied approximately 70 percent of the total domestic demand of 1,209 thousand short tons of zinc metal.

The total world production of zinc ore in 1971 was 6,078 thousand short tons with Canada, U.S.S.R., U.S. and Australia the leading producers. World zinc metal production in 1971 totaled 5,083 thousand short tons with the U.S., U.S.S.R. and Japan the leading producers.

Domestic mine production during 1971 (503 thousand short tons) was 6 percent lower than 1970 and preliminary totals for 1972 (481 thousand short tons) mine production point to a 4 percent decline from the

1971 totals. While the closure of five mines in 1972 was the primary cause for this decline, a new zinc-copper mine in Maine started operation in October of 1972. The closure of the electrolytic plant at Great Falls, Montana in 1972 caused a decline in smelter production of 150 thousand short tons. It is apparent that if this trend continues, the domestic reliance on imports will greatly increase in the future.

The long range projections of domestic zinc demand indicate that in the year 2000 the U.S. will need approximately 2,900 thousand short tons of slab zinc. Domestic reserves at the price of $.25 per pound are estimated at about 50,000 thousand short tons. However, unless means of commercially exploiting sources that are presently classified as "marginal" are developed, domestic reserves will have been largely exhausted by 2000. Extensive potential reserves, now classified as "inferred", exist in the zinc producing areas of the United States and would undoubtedly be developed under the incentive of a growing demand accompanied by price increases. Canada's resources at a price of $.25 per pound are 75,000 thousand short tons, more than double the total shown at the 1971 price of $.16 per pound.

Historically, the demand for zinc correlates with the general economic activity in most areas of the world. During the 1952-1971 period the average annual price of slab zinc in constant 1971 dollars varied between 14 and 26 cents per pound. The price of zinc has, historically, been approximately one third the price of copper.

In the United States, zinc is used in zinc-based alloys (34 percent) principally for diecastings; in galvanizing (27 percent) for corrosion protection of iron and ore steel; in brass and bronze alloys (21 percent) for sheet, plate and rod; in zinc oxide (10 percent) principally for rubber, pigment, sensitizing paper for photocopying and chemicals; as rolled zinc (2 percent) for battery cases, lithographic plates and architectural application; and miscellaneous (6 per-

cent) for zinc dust, other alloys, plant and animal nutrition, rayon, wood treating, and fungicides.

An important factor which will have a significant effect on both future demand and price is substitution. Zinc competes with many alternate materials, principally aluminum and plastics, for major uses. In periods of higher zinc demand, a price advantage could favor substitution of aluminum for galvanized sheet. Plastic coatings or paint can also be used in place of galvanizing to protect steel. Both aluminum and plastics are also potential substitutes in some die casting applications and for brass products.

5. Manganese

Manganese occurs in nature in combination with other elements in the form of ore minerals. The primary form found in the United States is manganiferous ore with a manganese content between 10 and 35 percent. These are mainly produced as a coproduct of iron and zinc. Manganese ore, a second form, is no longer a domestic source of supply because the cost of mining and treating these ores to produce a product equal in quality to the imported ores is higher than the delivered value of the foreign ores. Currently under study is a third form derived from sea nodules in the Pacific Ocean.

The United States depends upon imports to meet 95 percent of its domestic requirements. These imports are principally in the form of ore but are also in the form of ferroalloys. Major suppliers to the U.S. in 1972 were Gabon (26 percent), Brazil (19 percent), Republic of South Africa (15 percent) and Zaire (10 percent). With political unrest a future possibility in some of these countries, it is expected that the U.S. will depend upon Australia, India, Brazil and the Republic of South Africa to fulfill the large proportion of its future needs. Since manganese resources are distributed in a relatively large number of countries, sources of supply

do not appear to be a future problem.

During 1972, the United States demand totaled 1.26 million tons of manganese. Imports of 1.20 million tons, domestic production of .03 million tons and reclaimed scrap were used to meet this demand. A 1970 study conducted by the Bureau of Mines forecasts the U.S. demand in 2000 to be 2.1 million tons and the cumulative total from 1968 to 2000 to be between 47 and 53 million tons. The study also predicts that the rest of the world will need 18.3 million tons to meet its requirements in 2000 and the cumulative total from 1968 to 2000 will be between 335 and 407 million tons. With world reserves listed at 646 million tons there appear to be no foreseeable problems concerning a shortage of supply during the next 30 years.

Prices of manganese ores depend upon variable factors such as manganese content, chemical analysis and physical structure of the ore, quantity purchased and delivery costs such as freight and insurance. Prices of manganese ferroalloys vary according to the amount of contained manganese; content of carbon, silicon, and phosphorous; the physical sizes of the materials; and the quantity sold.

The 1970 Bureau of Mines study pointed out that the steady decline in price from more than \$200 to \$55 per short ton in the period from 1957 to 1968 was due to the increase in supply caused by the development of new deposits in Brazil, Australia, and several countries of Africa. Since supply is expected to remain approximately equal to demand, the price should remain constant through 2000. This is equivalent to less than three cents per pound. Refined manganese is priced at 35 cents per pound.

While the United States must rely heavily upon foreign sources to fulfill its demand in the future, the distribution of resources throughout the world, a more than adequate supply in relation to expected world demand and increasing competition among a large number of producing countries are factors that point

to a favorable picture concerning the price and availability of manganese through 2000.

Manganese ore is used in the United States chiefly for the production of ferroalloys, most of which is consumed by iron and steel plants throughout the U.S. Used chiefly as a desulfurizing agent in steel making, manganese also improves the rolling and forging characteristics of steel and adds to the strength, toughness, wear-resistance, hardness, and hardenability. Manganese is also added as a desulfurizing agent in the production of copper-nickel alloys and as a alloying addition to aluminum. Other areas of use include dry-cell batteries and manganese compounds for chemical processing.

6. Magnesium

Magnesium is the third most abundant structural element in the earth's crust. Commercial sources of magnesium raw material are widespread throughout the world and are so large that a tenfold increase in world demand would have little long run effect on availability or price.

About 90 percent of the magnesium consumed in the United States is in the nonmetallic form, mostly in high temperature refractories, pharmaceuticals, and in oxychloride and oxysulfate cements. Principal uses for the metal include the production of aluminum alloys and ductile iron, as a reducing agent for titanium and other metals, and for cathodic protection devices.

Two primary methods are employed to produce magnesium in the United States: The electrolysis of magnesium chloride from sea water, and the thermic reduction of dolomite with ferrosilicon. Dolomite, the double carbonate of magnesium and calcium and a sedimentary rock commonly imbedded with limestone, extends over large areas of the United States.

As of 1972 there were two domestic producers of magnesium metal and another company planning to enter

the business in 1973. One company in Texas uses sea water as its raw material source. The raw material source for the company located in Utah is the brine of the Great Salt Lake.

In 1971 the United States produced 123,000 tons of refined magnesium, the highest in the world where the total output was 257,000 tons. The U.S. and Norway are the primary consumers of refined magnesium metal. The former uses 99,000 tons and the latter 155,000 tons. The U.S. is a net exporter of magnesium metal.

World reserves of magnesium in magnesite are estimated to be over 2.6 million tons. World dolomite reserves are vast, and resources of lake and well brines are extensive. Sea water is available in virtually unlimited quantities in nearly all countries. It contains approximately 0.13 percent magnesium and is continuously replenished by drainage from land masses. All magnesium compounds and the metal can be extracted from sea water.

The present price for magnesium metal is approximately 38 cents per pound. This is only slightly higher than the 35.25 cent price which persisted from 1968 to 1970. Low cost electric power is a major contributing factor in the location of magnesium reduction plants and a 1970 report for the Bonneville Power Administration estimated that a pound of magnesium can be produced on the Texas gulf coast from sea water at an average operating cost of 21.7 cents.

A Department of Commerce study projects the domestic demand for magnesium metal in 2000 to be 460,000 tons equal to a 4.7 percent annual growth rate based on the 1968 demand of 106,000 tons. The forecast projects U.S. demand will be approximately one half of the total world demand as is the current trend.

Future technology will bring major improvements and new developments in magnesium extraction and fabricating techniques, and magnesium alloys.

The United States is expected to continue to provide virtually all of its needs for primary magnesium to meet the high or low forecast demand ranges for metal and nonmetal applications. A major factor in future supply-demand relationships for magnesium metal is the future price of aluminum since magnesium based alloys may be substituted for aluminum based alloys in some applications requiring light weight and moderate strength. More electric energy per unit of production is used in making magnesium than is required to make aluminum, and the long-term downtrend in the cost of electrical energy relative to other energy sources, services and products foreshadows a possible decline in the cost of magnesium compared with that of aluminum and other metals.

7. Chromium

The United States relies entirely on imports to meet its chromium requirements. The certainty of supply in a number of instances is speculative. The most urgent problem is establishing appropriate international relationships with regard to this commodity.

The importation of chromite from Rhodesia was resumed during 1972 although United Nations sanctions continued. Imports of chromium alloys reached a record high of 140,000 tons equivalent to 350,000 tons of chromite. As a result of this level of imports, domestic production of alloys containing chromium was about the same as in 1971, despite a significantly higher demand for chromium in alloys.

Domestic production of chromite ceased in 1961 when the last Government contract under the Defense Production Act was concluded. Since domestic ore is low grade it cannot compete with imported ore unless the price is above 15 cents per pound. Currently under development is a more direct means of using lower grade chromite in the production of stainless steel. This may be a factor in lowering unit costs

and increasing supply.

Government intervention has had a significant effect on the price of chromium. Stockpiling during the 50's drove the average price to above 10 cents per pound but at the conclusion of the program in 1967 the price dropped to 7 cents.

United States reserves at the 1971 price of 8 cents per pound are listed as zero while the world resources are 132 million tons. Domestic reserves which can be economically processed at a price of 15 cents per pound are listed at 670,000 tons.

In 1971 the United States consumed 0.4 million tons of the world total of 2.1 million tons. The U.S.S.R. and other communist block countries mined 39 percent of the world total of 2.2 million tons.

Estimated world reserves are more than adequate to meet both the probable and high forecast ranges for world demand in the near future.

As a pure metal and as a ferroalloy, chromium is used in the manufacture of stainless, tool and alloy steels, superalloys, cast iron, and nonferrous alloys; for refractory purposes, as chromite, for steel and glass manufacturing furnaces; and as a foundry sand. Major uses as a chemical include pigment manufacture, leather tanning, mordants and dyes, and electroplating. Consumption in 1971 by more than 1,000 firms was in: construction materials, 22 percent; transportation equipment, 21 percent; refractories, 13 percent; machinery, 13 percent; and other, 31 percent.

United States demand will be largely contingent on the level of steel production since chromium is a major alloying addition to stainless and other alloy steels.

Consideration of High Feasibility Materials

1. Copper-Zinc Alloys

Bronze alloys 220 (90 percent copper - 10 percent zinc) and 226 (87 percent copper - 13 percent zinc), red brass alloy 230 (85 percent copper - 15 percent zinc), and yellow cartridge brass alloy 260 (70 percent copper - 30 percent zinc) were tested as possible alternatives to 95 percent copper - 5 percent zinc gilding metal (penny bronze).

The experimental coining procedures are detailed in Appendix C. The alloys were blanked from strip without difficulty. A softening treatment prior to coining is necessary for any of these alloys. The temperature and time required to soften the blanks is greater as zinc content is increased beyond 5 percent. (See Annealing Summary - Table 4) As a result the annealing treatment for any of the experimental alloys would be more costly than for gilding metal blanks.

After annealing, all of the alloys responded to the cleaning treatment except alloy 260 which retained an orange-green appearance. The color resulted from dezincification of the surface - that is, zinc volatilizing from the surface of the blanks due to the high temperature. The other alloys assumed progressively lighter shades of red-orange compared with gilding metal, as zinc content increased to 15 percent.

The coining forces required to fill the image details of the experimental dies were similar to penny bronze for the 90 percent copper - 10 percent zinc and 87 percent copper - 13 percent zinc alloys. For 85 percent copper - 15 percent zinc and 70 percent copper - 30 percent zinc, coining forces were higher than those required for penny bronze (See Figure 5). This would cause increased die wear and an increased incidence of die cracking if either of these latter two alloys were substituted for penny bronze.

Wear-corrosion tests (See Appendix D for test description) show that resistance to surface deterioration increases with increasing zinc content. Higher zinc alloys are harder than the present cent alloy and should be slightly more resistant to nicking and scratches. All of the copper-zinc alloys tarnish rapidly.

All machines which utilize cents require no modification for higher zinc brass cents either alone or in combination with present cents.

It should also be noted that 70 percent copper - 30 percent zinc is more difficult to process to strip form than penny bronze. The higher zinc content and the high volatility of zinc mentioned above would create more difficult melting and casting conditions. This could create environmental problems for the workers and would require an extensive fume control system for the exhausts above the melting and casting facilities.

The selection of a higher zinc, copper-zinc alloy, must be regarded as a "holding action" rather than a solution to the current problem. Figure 3 indicates that the raw materials savings resulting from increasing zinc content are small. The financial benefits would probably provide only a temporary respite before the increasing price of copper necessitated that a second change be made. Furthermore, coin and strip fabrication costs are likely to increase slightly as a result of increased coining pressures and zinc volatilization.

Conclusion: Rejected as possible coining alloys.

Reasons : Lack of sufficient long range seigniorage protection against further increases in the price of copper, probable increase in manufacturing costs.

2. Aluminum Alloys

Aluminum alloys 1100, 3003, and 5052 have been tested for possible use as a substitute for the 95 percent copper - 5 percent zinc bronze presently used for the penny. The nominal compositions of the three alloys are summarized in Table 2. Alloy 3003 is the most readily available commercial aluminum alloy and is hardened by manganese. Alloy 5052 is representative of aluminum-magnesium alloys.

The three alloys were blanked from the strip without difficulty. Blanks of alloys 1100 and 3003 require no softening treatment prior to coining. Annealing of bronze one-cent blanks in FY 1973 cost the Mint approximately $500,000. Alloy 5052 requires a low temperature annealing treatment to soften the blanks in order to reduce the force required for coining.

In the experimental study, the necessity for blank cleaning was minimal. An alcohol rub to remove grease, metal fines and dirt was satisfactory. It may be possible to purchase clean, degreased, strip at a very small premium (less than one cent per pound for cleaning). If not, an alkaline or solvent degrease in standard Mint blank cleaning equipment can be accomplished at a lower cost than is incurred in cleaning annealed bronze blanks.

There are other important advantages of aluminum alloys, aside from the annual multi-million dollar savings in metal cost and significant savings in annealing and cleaning costs. First, the metal value in the cent would be less than 0.1¢ (Figure 4). This provides a very large margin of safety for future metal price increases. Another significant advantage is the low coining force required to fill the image details of coin dies (See Figure 6). This could result in reduced die wear, fewer cracked dies and, quite possibly, extended die life. Alloy 5052 would require a low temperature annealing treatment since the coining pressures

required for complete die fill are higher than those for penny bronze. Aluminum-magnesium alloys containing no chromium and, perhaps, less magnesium than 5052 are more readily coined without an annealing treatment.

A minor problem arose due to the easy metal flow characteristics of aluminum. Finning, or the appearance of a wire edge caused by material extruding between the die and collar, was initially observed prior to complete fill of the experimental dies. Finning is most severe on the softest material, alloy 1100, and this alloy was, therefore, eliminated from further consideration. This situation was greatly alleviated on alloys 3003 and 5052 using 1974 cent dies which have a slightly wider border than the experimental dies. Further studies using the 1974 cent dies indicated that the use of a ten cent upset segment to move metal away from the edge of the blank, prior to coining, eliminates this problem.

It may be necessary to reduce coining press speed slightly due to the weight of the aluminum blanks. Since the aluminum blanks are light, they are slightly more difficult to feed into the coining presses. Although a limit on press speed will have to be found experimentally, the presses may have to be run at speeds of 110-120 strokes per minute compared with 120-130 strokes per minute for bronze. Large quantities of aluminum alloy 3003 strip have been procured so that extensive tests can be performed to determine optimum press speeds. The increased cost resulting from a slight decrease in press speed is minimal compared with the potential savings in raw materials (Figure 4) and the savings which will result from the elimination of the coin blank softening treatment.

Although alloys 3003 and 5052 were both successfully coined into pennies and are readily available from several commercial sources, a series of aluminum-

magnesium alloys containing 0.8, 1.4, 1.8 and 2.5 percent magnesium are now being evaluated in order to determine which is the optimum alloy for coinage. These materials are not as hard as alloy 5052 and do not require a softening treatment prior to coining. Aluminum-magnesium alloys are somewhat easier to fabricate into strip than an aluminum-manganese alloy such as 3003. If a strip fabrication facility is to be included in the new Denver Mint, it is important that aluminum-magnesium alloys be thoroughly investigated before a final decision is reached on selection of the optimum aluminum alloy for coinage.

Because aluminum alloys form a natural protective oxide coating, they showed far better wear-corrosion characteristics than the present gilding metal alloy. Accelerated wear-corrosion tests (See Appendix D) which caused present pieces to lose 0.160 percent of their weight caused aluminum losses of only 0.012 to 0.038 percent, depending on the aluminum alloy chosen. This would correspond to a life four to seven times as long as the present cent alloy. This will be reduced somewhat by aluminum's greater susceptibility to scratches, nicks, and deformation. Considering all of these factors, durability is certainly acceptable.

It has been suggested that the color of aluminum would cause confusion when several coins are viewed on edge in a purse or pouch. Coloring the aluminum coin by anodizing was suggested as an alternative. The suggestion is not economically feasible. An aluminum cent would not have the orange colored edge nor the reeded pattern of the dime. The weight of the cent would be only 20 percent that of the five cent piece and, in time, the public will readily distinguish between the colors of aluminum and cupro-nickel. The latter is considerably grayer in appearance. Several countries, including Japan, Spain, and Poland, use coins of cupro-nickel and aluminum in sizes which are closer to one another than the U.S. cent is to the

nickel. If an aluminum alloy is selected for the penny, there is not expected to be any problem in distinguishing the cent from the dime or nickel.

Most machines which utilize cents require no modification to utilize aluminum cents alone or in combination with present cents. This is true of counting machines, cash registers, change dispensing machines, parking meters, and simple vending devices like bubblegum machines.

Sophisticated vending devices and automatic toll booth systems will require modification to accept aluminum cents, primarily because the low weight is not sufficient to trigger certain microswitches in these machines. These microswitches would have to be replaced by electro-optical switches (probably Light-Emitting-Diodes, LED's) which cost about $20 each plus installation. In addition, the present odd-cent machines would require replacement of the entire acceptor mechanism because of their choice of weight rather than diameter for the preliminary separation of dimes and cents.

This is not an extreme hardship for either the purchasers or manufacturers of vending machines. Both industries do almost all their business in higher denomination equipment. Odd-cent pricing is still controversial and very few odd-cent vending machines are in use at the present time.[3]

Automatic toll booths are serviced almost daily by manufacturer's representatives. Installation of LED switches on these machines could be accomplished as part of routine service visits. This would not be an extreme hardship for either the transit authorities or the automatic toll booth manufacturers. After modification, the toll booths would accept both bronze and aluminum cents.

The aluminum metal industry is a large consumer of electrical energy. The average aluminum refinery utilizes 8 kilowatt hours per pound of metallic aluminum and the total industry usage of 70 billion kilowatt hours in 1971 was approximately 4 percent of the total electrical energy used in the U.S. On the basis of total energy consumed considering all energy inputs - electrical, thermal and others including petroleum rich products consumed in the production processes - the aluminum industry accounts for 1 percent of the nation's total energy usage. Steel production requires almost 3 percent of the nation's total energy.

In 1940 the average refinery required 12 kilowatt hours per pound of aluminum. Today, the most modern smelters use about 6.5 kilowatt hours for the electrolytic reduction of aluminum oxide to extract one pound of metallic aluminum. A new commercial plant scheduled for completion in 1975 is expected, on the basis of preliminary testing, to produce a pound of aluminum with only 4.5 kilowatt hours of electricity.

Copper can be produced with one kilowatt hour of electrical energy per pound. However, because of aluminum's lighter weight, a given quantity of aluminum will yield 3.4 times more of the finished product than the same quantity of copper. On the basis of number of units of finished product. the ratio of electrical energy consumed in the production of aluminum compared with copper is now approximately 2/1 and is expected to decrease to 1.3/1.

In another respect, aluminum is an energy saving metal. Lighter vehicles, whether a truck, railroad car or airplane, mean less fuel consumption. The energy saved from the use of aluminum in vehicles comes primarily from petroleum which is likely to remain in short supply. On the other hand, domestic

coal, gas and hydropower are required to generate the electrical power to make aluminum. These have a better future supply outlook than petroleum.

Although several advantages and some disadvantages of aluminum alloys have been discussed, the potential savings in the annual cost of raw materials which exceeds $35 million at present production levels, the favorable future supply and price outlook and the ease of fabricating aluminum alloys to coins are the most compelling reasons for strongly considering aluminum as a substitute material for one-cent coinage.

Conclusion:	Acceptable material for one-cent coinage.
Reasons :	Readily fabricated into strip and coins; favorable long range supply outlook; annual multi-million dollar savings in raw materials; and has been accepted as a coinage material in other major industrialized countries.

3. Chromized Steel

Chromized steel is coated with a thin iron-chromium alloy layer. The resulting material has surface characteristics similar to a stainless steel but is available at a cost which is considerably lower than the 95 percent copper - 5 percent zinc penny bronze alloy.

Most coin handling machines which utilize cents require no modification to utilize chromized steel cents alone or in combination with present cents. This is true of counting and wrapping machines, sorting and counting machines, cash register change dispensing machines, parking meters, automatic toll booths, and simple vending devices like bubblegum machines.

Sophisticated odd-cent vending devices will require modification to accept chromized steel cents, primarily because of the magnets used in present machines. The magnets are designed to slow present cents as they move through the accept-reject mechanism and to reject steel washers, the most common slug encountered.

This is not an extreme hardship for either the purchasers or manufacturers of vending machines. Both industries do almost all their business in higher denomination equipment. Odd-cent pricing is still controversial and very few odd-cent machines are in existence at present.

Wear-corrosion tests (See Appendix D for description) indicated a probable life several times greater than the present gilding metal alloy. Although overall durability was excellent, the surface appearance after testing was mottled indicating uneven corrosion and possible discontinuities in the chromized layer. The presence of porosity in the surface layer was verified by examining cross sections of coins at high magnification.

A description of the coining experimental procedures is given in Appendix C. During the blanking operation, cupping was observed - that is, the blanks were convex in shape rather than flat. No softening treatment was performed on the material since it received a very high temperature anneal to form the iron-chromium surface layer during fabrication at Bethlehem Steel Corporation. Cleaning consisted of an alcohol rub to remove grease and dirt on the blanks. The blanks were upset using the standard penny upsetting machine.

The chromized steel is so hard that a very high pressure must be exerted to produce the proper relief on the coins. Even under the maximum safe pressure for the coining press, the relief was still not adequate (See Figure 6). This material is, therefore, unacceptable because of the expected short die life, press wear, and the inability to produce a high relief coin.

Furthermore, chromizing is a patented process of the Bethlehem Steel Corporation and the steel strip fabricating, powder rolling, diffusion annealing and auxiliary equipment would be very expensive to duplicate at a Mint facility. As a result, a reliable supply of high quality material could not be readily assured at a reasonable cost to the government.

Conclusion: Rejected as a suitable one-cent material.

Reasons : Very difficult to fabricate high relief coins, uncertain supply outlook for strip.

4. Bronze Clad Steel

Bronze clad steel has a similar appearance compared with bronze except for the gray edge. The material which was tested is steel coated with a layer of 90 percent copper - 10 percent zinc on each side. Gilding metal could also be used as the cladding alloy.

Cupping (blanks being bent into a convex shape) was observed during the blanking operation. The blanks will require a softening treatment at a temperature and time greater than that presently used for bronze to provide an acceptable hardness (See Table 4, page 60). Higher furnace temperature and/or slower speed through the furnace will result in higher annealing costs.

During testing, the heating cycle caused tarnishing. Hence, cleaning was necessary. The blanks were tumbled in the cleaning solution described in Appendix C for 15-20 minutes. The blanks did not clean readily so the process was repeated for a longer cleaning period. The blanks were still not clean; therefore, it is felt that another cleaning process must be found if bronze clad steel is to be used. The blanks were upset using the standard penny upsetting machine.

The coining force required to fill the experimental dies was significantly higher than any candidate alloy except chromized steel (See Figure 6, page 56). The required pressure was high enough so that a coin was not successfully produced with image and lettering completely filled even at the limitation of the available press tonnage. Without a more expensive annealing treatment to soften the steel core, the material would cause reduced die life and increased press wear. Furthermore, the image relief would probably have to be reduced even if the core were completely softened because, even at much slower speeds or higher furnace temperatures, the blanks could be not reduced in hardness to the level of annealed

gilding metal.

The economic benefits of bronze clad steel are highly questionable. The intrinsic value of the raw material would be decreased substantially compared with gilding metal but two factors tend to narrow the difference in cost. First, the cost of strip fabrication is almost 300 percent higher for the clad material compared with gilding metal. Second, gilding metal blanking scrap is readily recycled but bronze clad steel scrap has a very low recovery value. Table 5 shows that blank fabrication costs (including metal value) are 21 percent lower in the case of the clad material (assuming an optimistic recovery value for bronze clad steel scrap). This benefit could be offset by increased blank annealing and coining costs. Furthermore, under no circumstances would the savings in raw materials costs come close to approaching the savings which the government would realize if an aluminum alloy were selected for one-cent coinage.

Most machines which utilize cents require no modification for bronze clad steel cents alone or in combination with gilding metal cents. This is true of counting and wrapping machines, sorting and counting machines, cash register change dispensing machines, parking meters, automatic toll booths, and simple vending devices like bubblegum machines. Sophisticated odd-cent vending machines will require modification to accept bronze clad steel cents because of the magnets used to slow down coins and reject steel washers.

Bronze clad steel would probably be accepted by the public in spite of the dual colored edge if the image relief did not require major reduction. Low relief copper and brass clad steel coins have been utilized in West Germany for many years and, in the United States, the cupro-nickel clad copper coins are

now widely accepted.

The wear resistance of bronze clad steel coins would be approximately equal to that of the present penny. The steel edge would pit and rust slightly after many years but not to an unacceptable degree during the normal life of the cent (5-15 years).

Conclusion:	Rejected as a suitable one-cent material.
Reasons :	Very difficult to fabricate high relief coins; higher strip fabrication, blank annealing and coining costs, and low scrap recovery value may offset lower raw materials costs.

NEW DENVER MINT

Impact of Coinage Material on Plans

In view of the high probability that the one-cent coin alloy will be changed in the near future, the Bureau of the Mint faces the following alternatives with regard to the design of the new Denver Mint.

1. Proceed as planned to date. That is, construct a production facility for penny bronze strip in addition to a new coinage facility.

2. Proceed with site preparation and design of a new coining facility with the necessary support and administrative areas. Locate the coining facility on the site in such a manner that either a strip storage building or a strip production facility can be added as a second phase of the project.

3. Hold the Denver Mint project in abeyance until legislation on a new cent material is enacted. At that time, prepare new project plan.

The second alternative is the only one which will lead to orderly planning and the completion of the project in sufficient time to meet the nation's coinage requirements in 1980. Since the nature of the strip production facility is dependent on the new one-cent material, it would be irresponsible to proceed with the design and construction of a facility for production of penny bronze strip. Similarly, it would be imprudent to delay site preparation and design of a

new coining facility. It is forecasted that total coinage demand will increase to approximately 18 billion pieces by 1980. This is 100 percent more than the current demand. Unless a new coining facility is operable in 1980, the Bureau of the Mint's coinage production capacity will be insufficient to meet demand and a coin shortage will be the likely result. It is, therefore, absolutely necessary that the design of a new coining facility proceed without delay.

Since the evaluation of substitute materials for pennies has resulted in the conclusion that an aluminum alloy is the best alternative, a review of the merits of an in-house capability to produce aluminum alloy strip for penny blanks is required to justify the substantial capital investment in plant and equipment. The Mint's recent history of heavy reliance on outside vendors as sources for coinage strip has made orderly production planning difficult.

In the past, particularly in the last year, the Mint has had intermittent problems obtaining high quality coinage metal strip on a timely basis. The Mint now manufactures approximately 40 percent of its one-cent bronze strip and purchases the remainder from commercial vendors. Considering all denominations, the Mint produces approximately 50 percent of the strip required for coinage blanks.

In Fiscal Year 1973, the Mint returned to vendors approximately one million pounds of strip which did not meet the required chemistry and quality specifications. This adversely affected production scheduling and coining costs.

Purchases of strip from commercial vendors are made on a competitive bid basis. In order for prospective bidders to offer a firm price on these invitations, the Invitation for Bid must be for a specific number of pounds, a specified delivery rate and destination, and

gauge of strip. These specifications reduce the flexibility otherwise obtained by fabricating coinage strip in-house.

The purchase of coinage strip is based on the estimated demand for coins by the Federal Reserve Banks. Any changes in this demand require a corresponding adjustment in the production program. While the Mint has usually received the cooperation of strip suppliers in adjusting delivery schedules, such changes in contract, particularly changing the delivery rate, are not desirable for the contractor since they must plan their production schedules far in advance of the delivery date. In some cases it has been impossible for the contractor to decrease delivery rate and the Mint has had to accept the material and warehouse it for several months. On the other hand, a request for the contractor to increase his delivery rate due to an unforeseen surge in coin demand usually takes several weeks to accomplish, if at all. On several occasions the Mint has had to award an additional contract to obtain a higher delivery rate of strip.

The Mint has also occasionally had problems with the contractor failing to meet the required delivery date for strip. When this problem occurs, there is usually not enough lead time remaining for the Mint to award an additional contract to achieve the desired delivery date. This situation obviously causes a serious disruption in production of coins.

An intangible factor which should be considered is the possibility of labor strikes either at the commercial suppliers or by the transportation industry. The possibility of either natural calamities or changes in other product demands and requirements could affect the suppliers' ability or desire to provide the strip in a timely manner.

In recent months the commercial demand for copper alloy strip has been very high. This has resulted in

fewer competitive bids and contract awards have often been made even though one commercial firm submitted a bid. Prices are starting to increase and, if the current situation persists, the Mint will pay substantially more for strip fabricated by commercial vendors. Similar shortages of commercial strip fabricating capacity exist during high demand periods in the aluminum industry.

Recommendations

A plant should be constructed which will allow the Mint to manufacture most of its required aluminum alloy strip in the 1980's. An in-house strip fabricating facility is necessary in order that the Mint can be assured of a constant supply of relatively high quality strip at a reasonable price.

The Mint should proceed immediately with design of a coining and administrative facility for the new Denver Mint. In addition, plans should be formulated for the design and construction of a facility for the monthly production of 3.5 million pounds of aluminum strip on a three shift basis.

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8. American Metal Market, October 29, 1973.

9. American Metal Market, London Metal Exchange closing bid price.

COPPER PRICES (LME CATHODE) AND VALUE OF METAL IN ONE CENT COIN

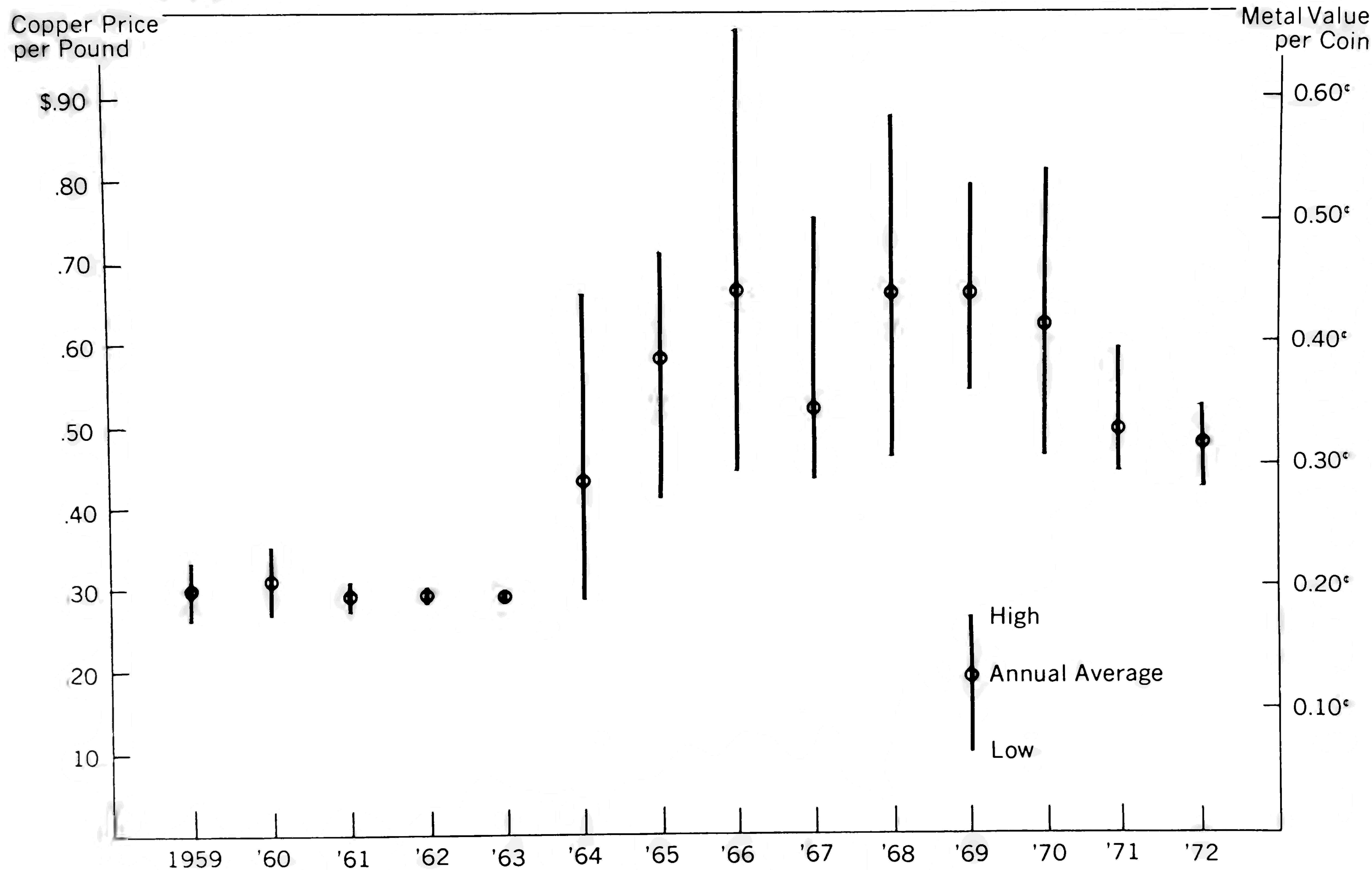


Figure 2
SEMI-MONTHLY AVERAGE PRICE OF CATHODE COPPER AND METAL VALUE OF ONE CENT PIECE

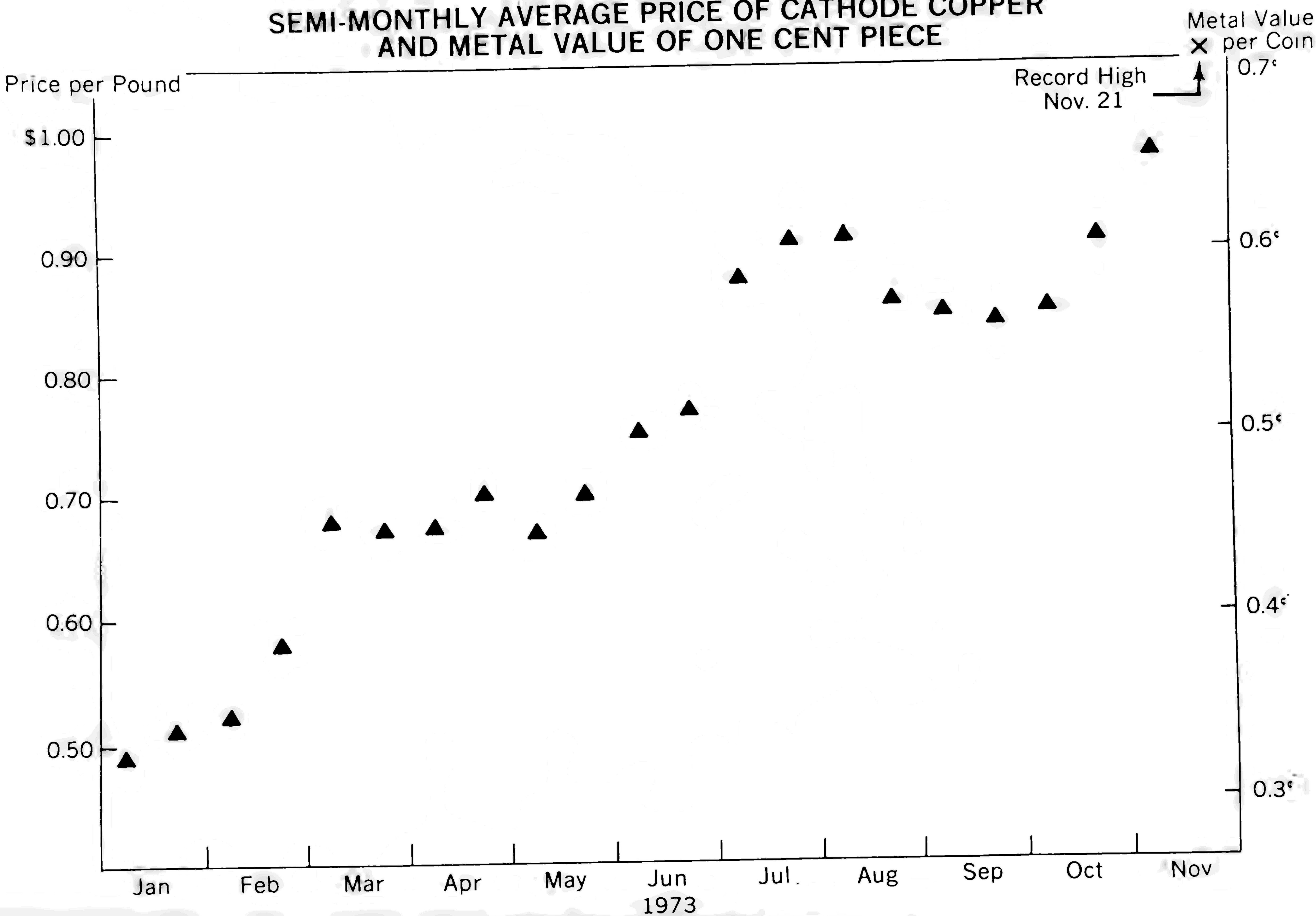


Figure 3

MATERIAL COST PER ONE CENT PIECE VS ZINC CONTENT

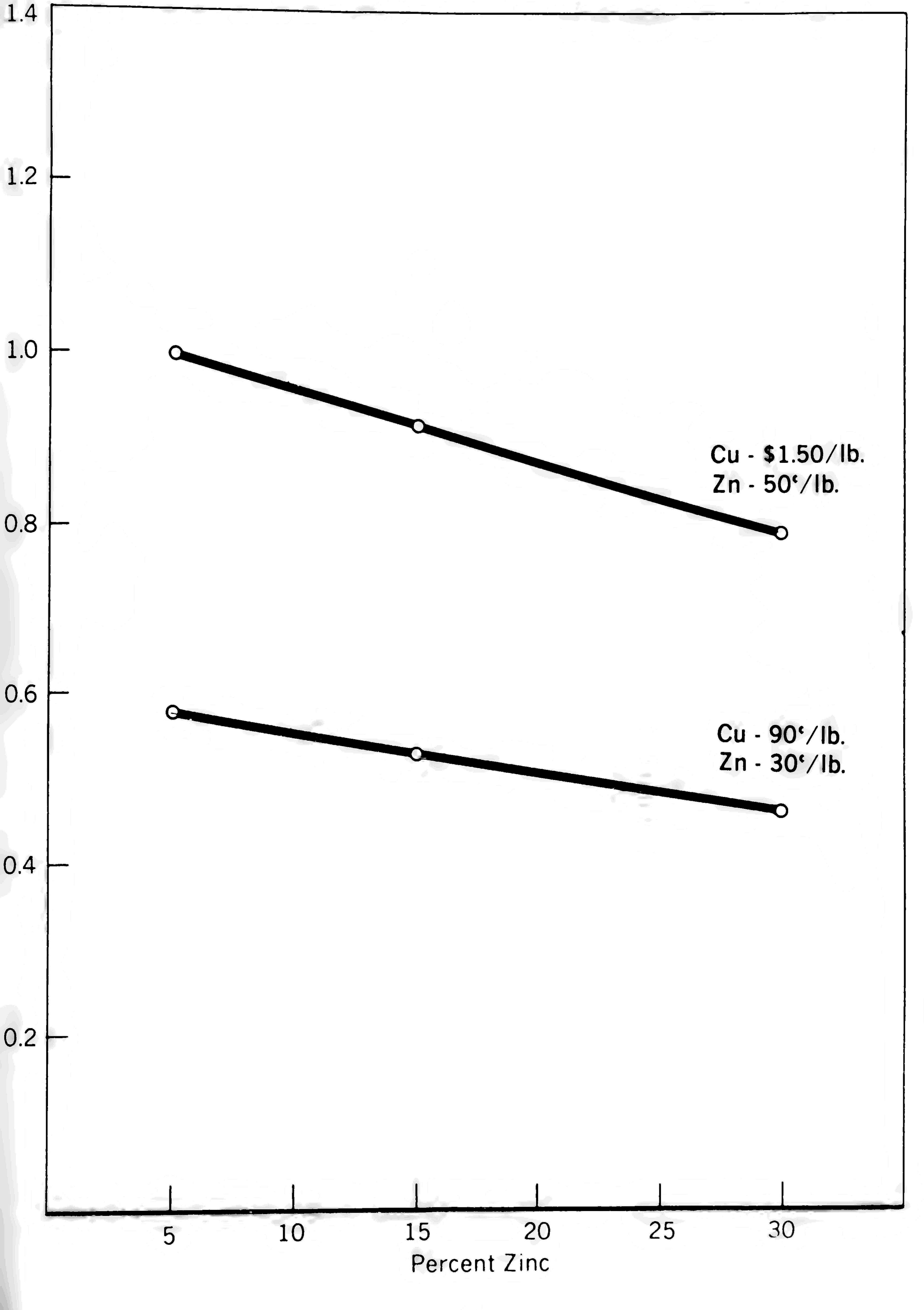


Figure 4

PROJECTED ANNUAL SAVINGS IN METAL COSTS FOR CENTS IF ALUMINUM IS SUBSTITUTED FOR BRONZE

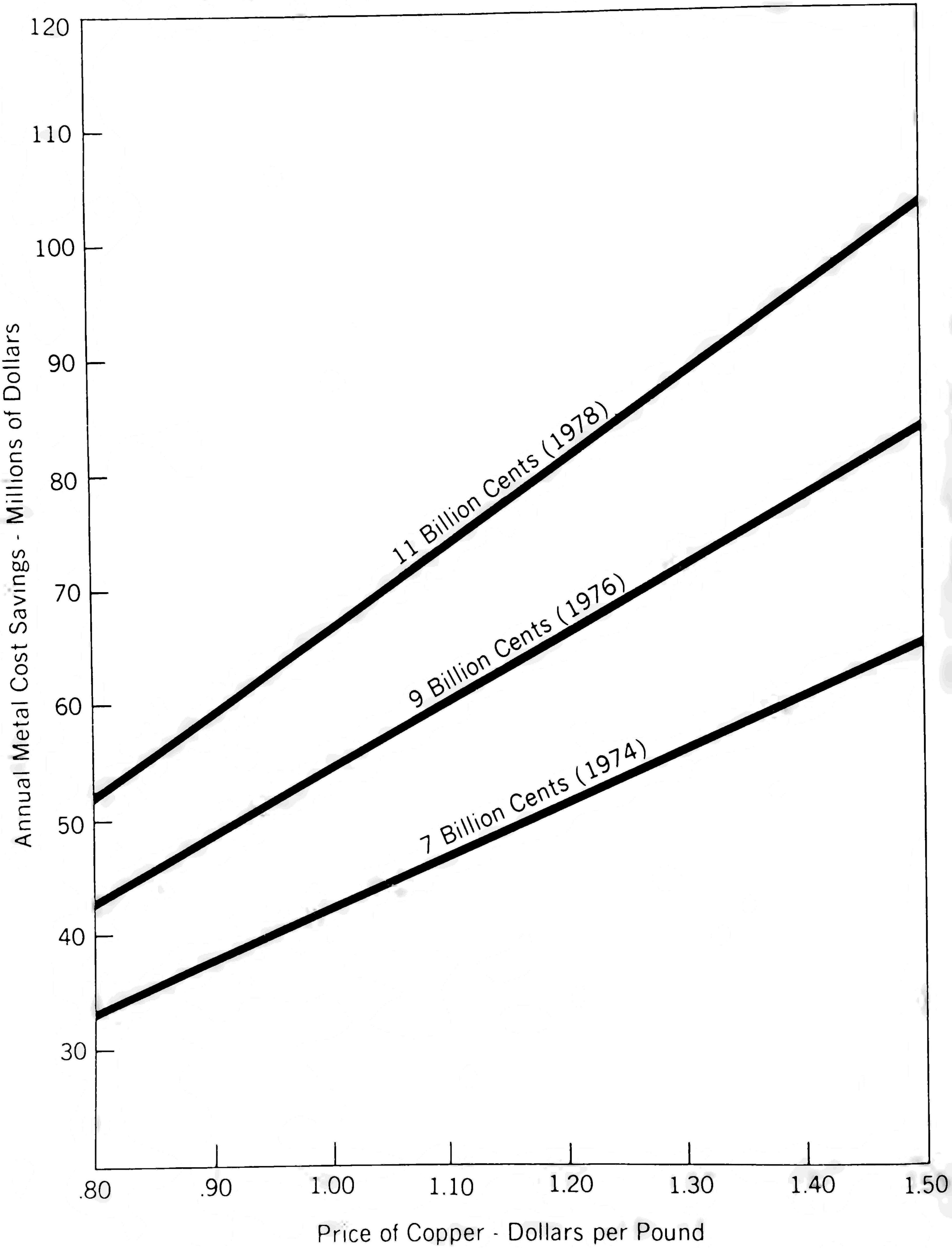


Figure 5

ANNUAL AVERAGE PRICE OF ALUMINUM INGOT AND VALUE OF METAL IN ONE CENT COIN[8]

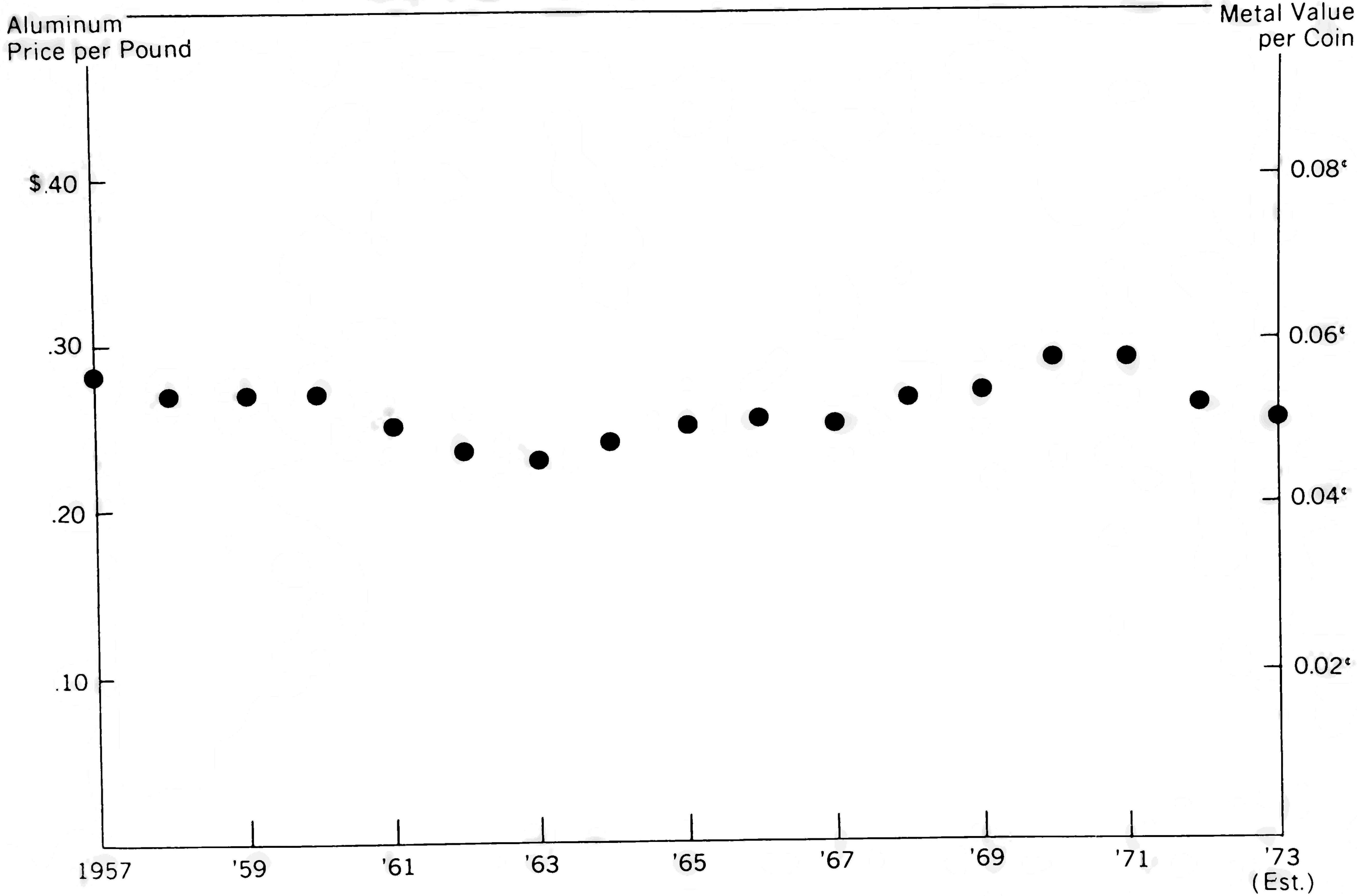
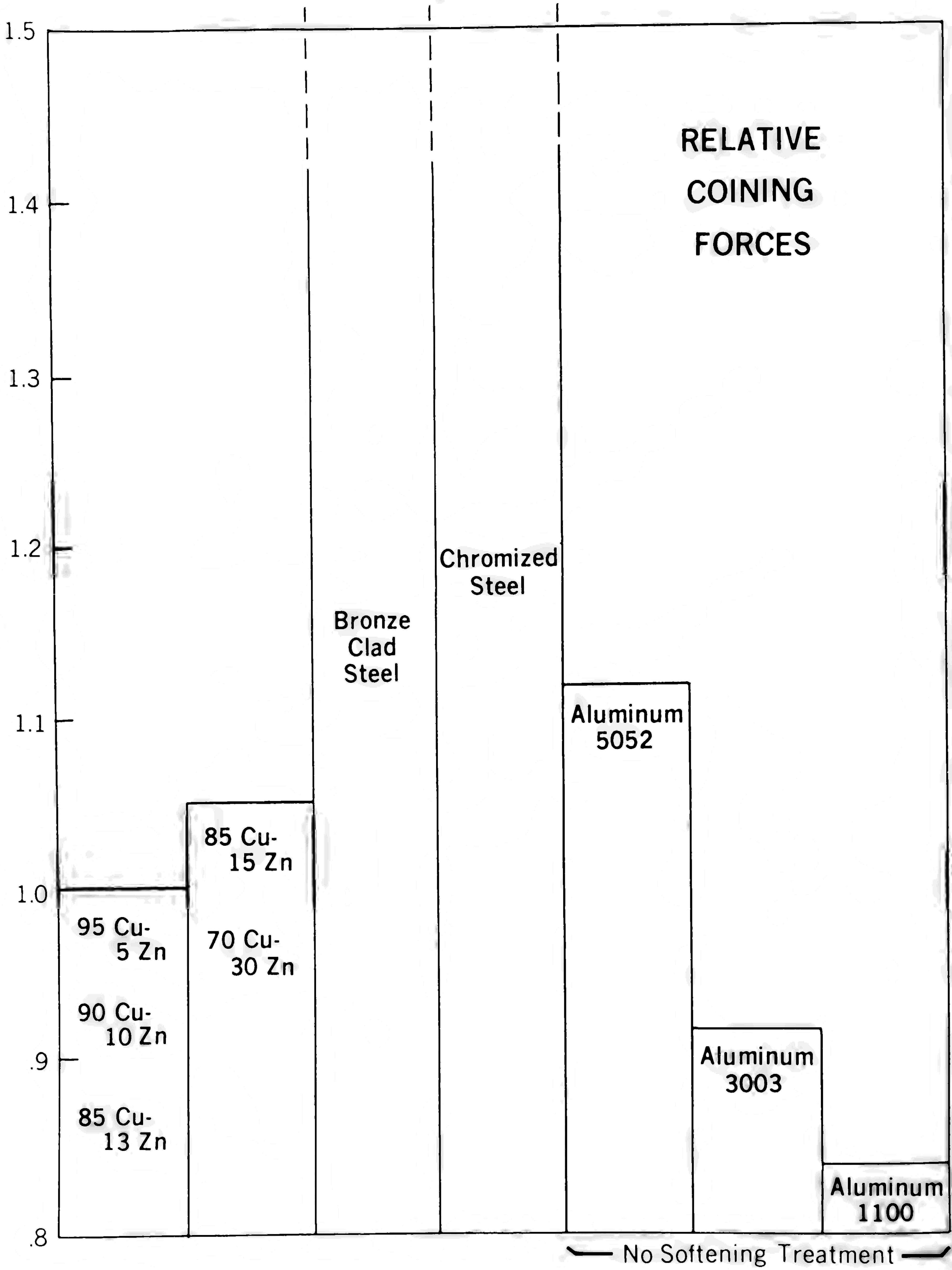


Figure 6



RELATIVE COINING FORCES
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
95 Cu- 5 Zn
90 Cu- 10 Zn
85 Cu- 13 Zn
85 Cu- 15 Zn
70 Cu- 30 Zn
Bronze Clad Steel
Chromized Steel
Aluminum 5052
Aluminum 3003
Aluminum 1100
No Softening Treatment

TABLE 1 - COMPARISON OF HIGH FEASIBILITY MATERIALS

	Penny Bronze	Copper - 30% Zinc	Bronze Clad Steel	Chromized Steel	Aluminum
Ease of Coin Fabrication	B	B-	X	X	A
Raw Materials and Strip					
Present Cost	X	C	B-	B+	A+
Present Availability	B	B	B	X	B
In-House Production Feasibility (long range)	A	B	B	X	B
Long Range Seigniorage Protection	X	X	B+	A	A+
Public Acceptability					
General	A	B+	B+	B	B-
Coin Machines	A	A	B	B	B-
Durability	B	B	B	A	B

A = Excellent
B = Good
C = Fair
X = Poor-Unacceptable

TABLE 2

Composition, %

Alloy	Aluminum*	Manganese	Magnesium	Chromium
1100	99.0 minimum			
3003	96.8 minimum	1.2		
5052	96.0 minimum		2.5	0.25

* Small quantities of common impurities such as iron, silicon, copper and zinc may be present.

(AMOUNTS IN THOUSANDS OF SHORT TONS AND REFLECTING 1971 DATE)

	Aluminum	Chromium	Copper	Iron	Magnesium 2/	Manganese 3/	Iron
Ore							
A. U.S. production	Bauxite-512	0	1,522	54,300	123	38	503
B. Imported to U.S.	Bauxite-3029 Alumina-1315	403	181	27,700	4	1,147	467
C. Primary suppliers to U.S.	Bauxite: Jamaica Surinam Dom. Rep. Alumina: Australia Surinam Jamaica	So. Africa USSR Turkey Philipp.	Peru Chile So. Africa	Canada Venezuela Brazil Liberia	Canada	Gabon Brazil So. Africa Zaire	Canada Mexico Peru Honduras
D. Primary world producers	Jamaica Australia Surinam	USSR So. Africa Turkey Philipp.	US Chile Canada	USSR US Australia	US USSR Norway	Comm. Block So. Africa Brazil Gabon	Canada USSR US
E. Total world production	Bauxite-14396 Alumina-12788	2,184	6,535	488,400	257	9,998	6,078
Refined Metal 4/							
A. Approximate price per pound	27	33 (ferrochrome)	101	4	38	35	28
B. U.S. demand	4,125	220	2,072	108,100	938	1,170	1,209
C. U.S. production	3,925	216	1,800	81,400	879	809	766
D. Imported to U.S.	690	54	164	300	84	186	325
E. Primary suppliers	Canada Norway	So. Africa	Canada Chile	Misc.	Greece Ireland	Misc.	Canada Australia
Supply-Demand Projections 1/							
A. Estimated U.S. reserves	13,000	1,800	108,000	18,000,000	15,000	0	50,000
B. Est. cumulative U.S. req. to 2000	370,000	19,100	92,700	3,200,000	43,000	47,000	62,000
C. Est. free world reserves (incl. U.S.)	2,405,000	771,600	379,000	141,900,000	250,000	394,000	110,000
D. Est. cumulative free world req. (incl. U.S.) to 2000	1,000,000	82,770	392,600	11,868,000	201,400	300,000	212,000

1/ Estimated reserves are based on the highest price reported in the U.S. Industrial Outlook. As the price of metal increases the amount of potentially recoverable reserves increase.
2/ Ore quantities represent metal only; refined quantities include non-metallic totals.
3/ Ore amounts represent magniferous ore for the U.S.; refined amounts represent manganese ferro-alloys.
4/ Difference between production plus imports compared with demand may be accounted for by scrap, industry stocks and exports.

TABLE 4 - Annealing Summary

		Hardnesses in Rockwell 15T Units			
Alloy	Gage	Before Annealing	1100°F	1200°F	1300°F
210 Bronze	.0500 inches	88.0	46.0	45.0	43.0
220 Bronze	.0500	88.0	54.0	50.5	49.0
226 Bronze	.0510	89.0	56.5	52.5	51.0
230 Brass	.0505	85.0	57.5	55.0	52.0
260 Brass	.0500	90.0	54.0	51.5	49.5
Bronze-Clad Steel	.0530	79.0	79.0	78.0	77.0
Chromized Steel	.0460	72.5	72.5	72.5	72.5
1100 Alum.	.0480	56.5			
3003 Alum.	.0485	65.0			
5052 Alum.	.0500	79.0			

Note: A high temperature softening treatment is not required for productio of high relief aluminum alloy coins.

TABLE 5 - Cost Comparison for One-Cent Blanks of Penny Bronze and Penny Bronze Clad 10% on Both Sides of Steel

	Copper-5% Zinc	Copper-5% Zinc Clad Steel
Metal Cost	\$0.87 per pound	\$0.26 per pound
Strip Fabrication Cost	0.09	0.26
Gross Strip Cost	\$0.96 per pound	\$0.52 per pound
Less Scrap Value -		
gilding metal	- 0.44	-0.05
composite		-0.02
Net Cost of Blanks	\$0.52 per pound	\$0.45 per pound
Density	0.320 lbs. per $inch^3$	0.291 lbs. per $inch^3$
Net Cost on Volume Basis	\$0.166 per $inch^3$	\$0.131 per $inch^3$
Relative Cost Per Blank	1.00	0.79

Data used in calculations

Raw material costs: Copper - \$0.90 per pound; Zinc - \$0.30 per pound; Steel - \$0.10 per pound.

Percent scrap generated in strip fabrication: Penny bronze - 28%; Penny bronze clad steel - 35%.

Percent scrap generated in blanking: Both materials - 28%.

Value of scrap: Penny bronze - 90% x metal value; Penny bronze clad steel - 20% x metal value (This may be an optimistic estimate).

Appendix A

A STUDY OF FUTURE CENT DEMAND AND MATERIALS - PROJECT PLAN

Statement of Problems

1. Potential negative seigniorage and hoarding of cent.
2. Implications on new Denver Mint strip facility.
3. Lack of satisfactory short term (as related to production scheduling and inventory requirements) and long term (as related to coining capacity requirements) demand forecasts.

Scope of Study

1. Test and analysis of promising substitute cent materials including changes in size and copper content.
2. Study of the feasibility, acceptability, and benefits and impact of an additional coin denomination between the 1¢ and 5¢ pieces.
3. Analysis of the coin distribution and consumption system to improve our ability to predict short and long range coin demands.
4. Forecast of cent requirements for 1980-1990.
5. Recommendation of strip production or storage facility for the new Denver Mint.
6. Recommendation for new coinage legislation.

Methodology

1. Alternate cent materials and sizes.

   a. Review of potential high feasibility materials with respect to raw material availability and costs, strip and coinage production costs, ease of fabrication, acceptability, longevity, compatibility with present coinage, counter-

feiting potential, energy consumption and vending machine use.

b. Perform preliminary screening of available alloys and establish a priority list of high feasibility materials.

c. Perform laboratory scale coin fabrication studies on several high feasibility materials and sizes.

d. Perform pilot scale coin fabrication studies on the most promising of the high feasibility materials and sizes above.

e. Present samples for review and approval by Treasury and Federal Reserve System officials.

2. Demand Analysis

a. Review the coin ordering, storage, and distribution system and past bank usage data.

b. Attempt to correlate coin usage with certain selected short and long range economic and expenditure indicators.

1. Determine the number of coins in circulation, by denomination.
2. Determine the coin loss rate, particularly of cents.

c. Perform a market analysis of the acceptability and impact of a new coin denomination on demand.

3. Review the impact of the above on long term coining, strip production and storage capacities.

Schedule

Complete laboratory scale cent alloy study, November 1, 1973.
Complete pilot scale most promising alloy study, April 1, 1974.
Complete impact of new coin denomination study, January 1, 1974.
Complete cent demand study, February 1, 1974.
Complete final report and recommendations, June 1, 1974.

Staffing

Members of the study committee will be as follows:

Bureau of the Mint
Dr. Alan J. Goldman - Chairman
Dr. George E. Hunter
William J. Murphy
Deborah A. Duke
Francis R. DeLeo

Office of the Secretary of the Treasury
Richard Schmidt
Homer V. Hervey
C. William Smith, Jr.

Board of Governors of the Federal Reserve System
James L. Stull

Approved: J. Elton Greenlee
Acting Assistant Secretary for Administration

Date: AUG 31 1973

Approved:
Acting Assistant Secretary for Enforcement, Tariff and Trade Affairs and Operations

Date:

Approved: E. Maurice McWhirter
Associate Director, Division of Federal Reserve Bank Operations
Board of Governors of the Federal Reserve System

Date: 9/5/73

Concur:
Director of the Mint

Date: 8/31/73

Appendix B

A BILL

To authorize the Secretary of the Treasury to change the alloy and weight of the one-cent piece.

<u>Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled</u>, That section 3515 of the Revised Statutes, as amended (31 U.S.C. 317), is further amended by designating the existing section as subsection (a) and by adding a new subsection (b) to read as follows:

"(b) Whenever the Secretary of the Treasury determines that the use of copper in the one-cent piece is no longer practicable, he may change the alloy of the one-cent piece to not less than 96 per centum of aluminum and such other metals as he shall determine. The one-cent piece authorized by this subsection shall have such weight as may be prescribed by the Secretary."

Appendix C

EXPERIMENTAL PROCEDURES FOR COINING STUDIES

Strips of each alloy were received in the hard "as rolled" condition and samples were taken to verify chemical composition, thickness, and Rockwell hardness. A 15 kg load hardness test was used. Several feet of each copper-zinc and aluminum alloy were cold rolled at the Philadelphia Mint to standard penny strip thickness of 0.0495 ± 0.0015 inches. The bronze clad steel and chromized steel sample strips were received at the proper thickness. The strips were then blanked using standard gilding metal blanking tool clearances of approximately 7 percent. Blank diameter and hardnesses were measured.

The blanks were softened by heating to various temperatures in a continuous belt annealing furnace in order to simulate production annealing conditions and hardnesses were again recorded. Approximately sixteen minutes were required to travel through the furnace hot zone. It is estimated that the temperature of the blanks reached the furnace temperature for a small fraction of this period.

In preparation for coining, the blanks were cleaned to remove tarnish, grease, or dirt. The bronze alloys and bronze clad steel were tumbled in a cleaning solution of soap bark and cream of tartar for 15 to 20 minutes and the aluminum alloys and chromized steel were rubbed clean with a cloth saturated with alcohol. Some of each type of blank were upset using the standard penny blank upsetting machines and others were tested in the nonupset condition. Aluminum was later tested using several edge upset configurations.

Blanks of each alloy and gage, upset and nonupset, were then coined using nonsense dies, and the tonnage

required for complete fill of image detail and lettering was recorded. In some cases, complete fill could not be achieved. The nonsense dies were designed to simulate the actual penny dies with regard to relief and location of images and lettering. In this way, coining characteristics of the alloys could be compared relative to one another without creating a large number of potentially valuable numismatic oddities, i.e., pennies stamped of alloys other than 95 percent copper - 5 percent zinc, gilding metal. Finally, 1974 cent dies were used to strike a carefully controlled number of aluminum alloy coins.

Appendix D

EXPERIMENTAL PROCEDURE FOR WEAR-CORROSION TESTS

The accelerated wear-corrosion tests involved exposure of the experimental alloys to conditions which approximate actual service for circulating coinage. From extensive weighing of circulating cents drawn from circulation, it is concluded that the test simulates 1 1/2 to 2 years of service.

Note that blanks were utilized in lieu of coins for reasons of security. Although the absolute weight losses would have been higher had coins been used, the comparison is valid for blanks since the relative losses in weight rather than absolute losses (which are a function of contour) are relevant for purposes of this study.

Five hard, upset, blanks representing each experimental alloy and five gilding metal blanks were weighed and subjected to 48 hours of tumbling in a ball mill containing 450 milliliters of SAE 30 oil, 150 milliliters of artificial sweat solution and 3 pounds of sea sand. The sweat solution consisted of: 10.00 grams NaCl; 1.25 grams Na_2HPO_4; 1 milliliter lactic acid; and 1 liter distilled water.

The blanks were weighed before and after tumbling in order to determine the weight loss. A comparison was made between the percentage weight losses for the experimental alloys and for the gilding metal blanks.